Simulation of Landscape Pattern of Old Growth Forests of Korean Pine By Block Kriging[1]

Wang Zhengquan (王政权)　Zhang Yandong (张颜东)　Wang Qingcheng　(王庆成)

(Northeast Forestry University, Harbin, 150040, P. R. China)

Harbin Li

(USDA, Southern Forest Research Station, USA)

Abstract　The study area was located in Liangshui Natural Reserve, Xaoxing'an Mountains, Northeastern China. Korean pine forests are the typical forest ecosystems and landscapes in this region. It is a high degrees of spatial and temporal heterogeneity at different scales, which effected on landscape pattern and processes. In this paper we used the data of 144 plots and semivariogram to analyze spatial heterogeneity of old growth forests of Korean pine in landscape level. Model for forest variations by isotropic semivariogram is linear with sill. The spatial heterogeneity is dependent on scales and directions in Korean pine forests. Patterns of forest types in space were resulted from complex interactions between physical and biological forces. We used 20 metres for interpolation interval to estimate the values of unsampled area. Comparing the results with field data, block kriging and mapping are an effective techniques to simulate landscape pattern.

Key wards: Korean pine, Semivariogram, Block kriging, Simulation, Landscape pattern

Introduction

Landscape can be considered a spatially heterogeneous area, and spatial pattern refers to the arrangement of structural heterogeneity of environments, resource and biological systems in space (Forman et al 1986, Turner 1987, 1989, Risser 1987, Turner et al 1991). Turner (1987, 1989) considered that spatial pattern has important consequences regarding the effective dispersal of organisms among landscape elements and the spread of disturbance across the landscape. In landscape ecology, spatial patterns were caused by different natural processes and interactions under different scales, and were distributed regularity in landscape mosaic. Therefor, it is one of the main questions in landscape ecological studies(Li et al 1988, Wiens 1988, Turner 1989). There exists a vertical and horizontal variations of vegetation(e.g., forest stands) and other resource (e.g., soil) in landscape level. These variations are commonly in landscape and have two components: one is the structural component(e.g., patch shapes, size) which can be identified, another is the random which is unknown and uninterpreted(Burrough 1983). Both of which are the center in landscape studies(Forman et al 1986).

Landscape structure must be identified and quantified in meaningful ways before the interactions between landscape pattern and ecological processes can be understood(Turner 1989, 1991). There are many quantitative ways for spatial pattern analyzed (Romme 1982, O'Neill et al 1988, Turner 1988, 1991, Milne 1988, Burrough 1986, Gardner et al 1987) and spatial simulation of landscape pattern and changes (Turner 1987, 1988, Bartrell et al 1991, Merriam et al 1991, Gardner et al 1991), which were developed during past over decade. Spatial statistics, e.g. spatial autocorrelation, is one of the spatial models. Semivariogram, as spatial autocorrelation, examines spatial variation and correlation of natural phenomena(Matheron 1963, Journel et al 1978, Webster 1985, Cressie 1991). Semivariogram is based on the theory of regionalized variables and while recent applications of which in ecological research have demonstrated its effectiveness to summarize spatial data (Robertson 1987, Robertson et al 1988, Palmer 1988, Fortin et al 1989, Legendre et al 1989, Levin et al 1989, Rossi et al 1992). One of the prime reasons for obtaining a semivariogram is to use for spatial estimation, e.g. kriging (Journel et al 1978, Webster 1985). Kriging is a technique of making optimal, unbiased estimates of regionalized variables at unsampled locations using the structural properties of the semivariogram and the initial set of data values(Journel et al 1978, Trangmar et al 1985). Therefor, kriging can be

used for landscape simulation and mapping spatial pattern(e.g., patches) by landscape(or spatial) data.

Korean pine(*Pinus koraiensis*) forests, which often mixed with hardwoods, e.g. birch(*Betula costata*), ash(*Fraxinus mandshurica*), walnut (*Juglans manshurica*), corktree(*Phellodendron amurense*), linden (*Tilia amurensis*), typical old growth forest ecosystem(Chen 1982, Li et al. 1993, Wang et al. 1996), is a main important forest landscape in Northeast Parts of China. It is high degrees of spatial and temporal heterogeneity at different scales(Wang et al 1997), which effected on landscape pattern and processes. There are some different landscape patterns in Korean pine forests. The distribution of species, structures of age, energy, nutrient cycling, and regeneration would be related to the sizes, shapes of patterns. But, studies of landscape ecology, specifically, spatial pattern for Korean pine forest have been lacking during the past. We should know the development and dynamics of spatial heterogeneity, interactions and exchanges across heterogeneous landscape, the influences of spatial heterogeneity on biotic and a biotic processes, and the management of spatial heterogeneity(Turner 1989) at different scales in landscape of Korean pine forests. we may understand well the trues of structures, functions and dynamics of Korean pine forest ecosystems in landscape level.

In this paper we use semivariogram model to analyze spatial heterogeneity and block kriging(Journel et al 1978, Webster 1985, Trangmar et al 1985) to simulate landscape pattern of Korean pine forests, and discuss the relations between spatial heterogeneity and patterns. We specifically discuss (1) the characteristics, degrees and scales of spatial heterogeneity; (2)kriging and mapping for landscape patterns, and (3)the sizes and shapes of spatial patterns of Korean pine forests.

Theory of Block Kriging

The method of estimation embodied in regionalized variable theory is known in earth sciences as kriging, after Krige(1966), who first devised it empirically for use in the South African goldfields. It is essentially a means of weighted local averaging in which the weights are chosen so as to give unbiased estimates while at the same time minimizing the estimation variance. Kriging is this sense optimal(Webster 1985).

In block kriging, a value for an area or block with its center at X_o is estimated. The kriged value of property Z for any block V is a weighted average of the observed values X_i in the neighborhood of the block, i.e.,

$$\hat{Z}(V) = \sum_{i=1}^{n} l_i Z(X_i) \qquad (1)$$

where n is the number of neighboring samples $Z(X_i)$ and λ_i are weights applied to each $Z(X_i)$. The weights are chosen so that the estimate $\hat{z}(V)$ of the true value $Z(V)$ is unbiased, i.e.,

$$E[\hat{Z}(V) - Z(V)] = 0 \qquad (2)$$

and the estimation variance σ_v^2 for block V is minimized, i.e.,

$$\sigma_v^2 = VAR[\hat{Z}(V) - Z(V)] = \text{minimum} \qquad (3)$$

The weights placed on each neighboring sample sum to 1, and their unique combination for which σ_v^2 is minimized can be obtained when

$$\sum_{i=1}^{n} \lambda_i \gamma(X_i, V) + \mu_v = \gamma(V, V) \qquad (4)$$

and unbias conditions is $\sum_{i=1}^{n} \lambda_i = 1$. The estimated variance is shown in below

$$\sigma_v^2 = \sum_{i=1}^{n} \lambda_i \gamma(X_i, V) + \mu_v - \gamma(V, V) \qquad (5)$$

where $\gamma(X_i, V)$ is the average semivariance between the sample points X_i in the neighborhood and those in the block V, $\gamma(V, V)$ is the average semivariance between all points within V (i.e., the within block variance of classical statistics)(Journel et al 1978), and μ_v is the Lagrangian parameter associated with the minimization. Eq.(4) is the n+1 equations of the kriging system. Kriging thus provides not only unbiased estimates of minimum variance, but also a measure of the estimation variance. In this respect it is superior to other methods of interpolation(Journel et al 1978, Webster 1985, Isaaks et al 1989).

The most common use of block kriging has been for the production of maps of spatially dependent properties. Spatial patterns and variations can be seen clear on the kriging maps. Most applications of kriging in mining science (Journel et al 1978, Isaaks et al 1989), soil science (Webster 1985, Trangmar et al 1985), ecology (Robertson et al 1987. 1988, Rossi et al 1992) used kriging maps to show spatial patterns in research regions or sampled locations. Block kriging is an effectiveness methods of interpolation for spatial data(Isaaks et al 1989).

Study Site and Data

The study site was located the old growth forests of Korean pine , at the Liangshui natural reserve of Xaoxing'an Mountains, E128° 48'30" to E128° 55'50", N47°

7'39" to N47° 14'22", in Northeastern China. It is a typical forest vegetation and landscape in this region(Wang et al 1996, Li et al 1993). The climate is terrestrial temperate and monsoon climate, average annual temperature is -0.3°C, and temperature range from -43°C to 38°C, and annual accumulated temperature($\geq$5°C) is about 2000°C. Annual precipitation is 676 mm, relative humidity is 0.78, and evaporation is 805 mm. The range of frost free season is from 100 to 120 days. The typical soil under forests is dark-brown soil.

The total area of Liangshui natural reserve is about 6394 ha, most stands are mixture between conifer(e.g., pine (*Pinus koraiensis*), spruce(*Picea mandshurica, Picea koriensis*), and fir (*Abies nephrolepis*)) and hardwoods(e.g., ash, birch, oak, linden, corktree, and walnuts). There are twelve forest types which were distributed in landscape(Li et al 1993), its age range distribute from 200 to 300 years, and over 400 years for the dominant species of Korean pine.

The area size for this study is 144 hm$_2$, selected from airphoto which was taken in 1983, located in undisturbed old growth stand. For simulating landscape pattern, we established 12 transects from south to north in 1995, and setup 12 plots in each transects. The total numbers of plots is 144 and each plot size is 30×30 m in sampled region. The sampling interval between transects, and between plots are 100 m(Fig.1). In each plots, we measured and named each trees, height, DBH, base area, age, cover rate, densities, soil, and plants. We also measured and defined the elevations, aspects, slopes, and micro-topography.
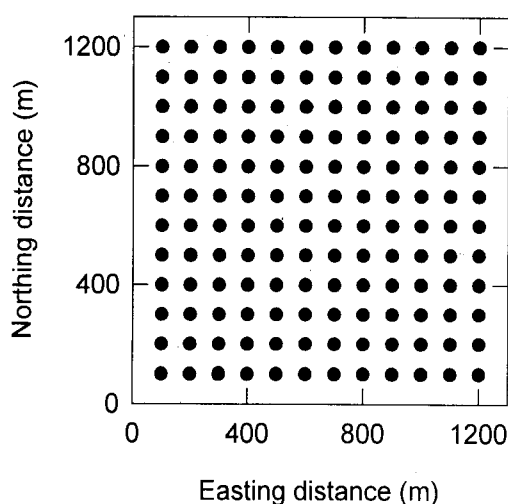

Fig. 1. Diagram of plot locations sampled in the old growth forest of Korean pine

In datasheet of 144 plots from fields, we calculated base area of each species and stand compositions, in order to define and name the stand types in each plots. Geostatistical analysis, calculating semivariograms of forest types from field data, fitting various models to semivariograms, and kriging, were performed using GS+(Gamma Design 1995) software. The landscape heterogeneity were first analyzed by the parameters of semivariogram, e.g., range, sill, nugget, and fractal dimension. The four parameters are useful tools for quantification of spatial heterogeneity at different landscape levels. Specifically, nugget variance to sill ratio reflects the proportion of nugget variance in total variance(Robertson 1988, Li et al 1995). Where this proportion approaches 0, spatial dependence is very high, there must be spatial patterns in sampled region. Where this proportion approaches 1, apparent spatial dependence is very low, indicating that spatial pattern occurs mainly at scales smaller than the average distance in the first lag interval, in our case 100 m.

The semivariogram of forest types, fitting by the models of theoretical semivariograms, can be considered as landscape model for describing variations of forests in space in sampled region. We use ordinary block kriging(Isaaks et al 1989) with a block size of 20 m across the field to interpolate unsampled locations and produce kriging maps.

Results and Discussion

Results

There are five forest types, Spruce-fir forests(18%), Spruce-Korean pine forests(48%), Libbed birch-Korean pine forests(9%), Amur linden-Korean pine forests(22%), Mongolian oak-Korean pine forests(3%), which were distributed in 144 plots and indicated different forest ecosystems, or forest patches.
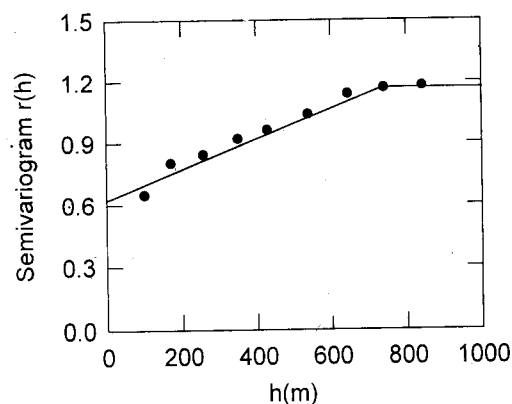

Fig. 2. Semivariogram of forest types at landscape levels. The fitting model is linear with sill

The variable of forest types was examined by semivariogram analysis. Values of the parameters of

semivariogram and fitting model are given in Table 1. and isotropic semivariogram (Fig.2). four perpendicular directions used in anisotropic semivariograms(Fig.3) were constructed. Kriging map, by using theory model(linear with sill in Table 1) of semivariogram, for simulation landscape pattern of Korean pine forests is illustrated in Fig.4.

Discussion

There was a high degrees of landscape heterogeneity observed in old growth forests of Korean pine. Semivariogram for forest types show increasingly strong autocorrelation at distances of less than 718 m(Fig.2) in landscape level. This means that forest patches in this landscape may be about 720 m. Beyond that distance the semivariogram was essentially flat. indicating the region where forest types among each may be independence in space. The nugget variance(C_0=0.6200) to sill ($C_0 + C$ = 1.2000) ratio show that the spatial heterogeneity of random is about 52%, and the degree of spatial dependence was moderately at 48%. By examining the balance between these two

components, one can gain insight into spatial heterogeneity at different scales. The forest types at small scales, independence less than 100 m, were operated by inter-processes (e.g., competition, regeneration inside stands) or sampling error(Trangmar et al 1985. Webster 1985). and the scale-dependence between 100 metros to range (718 m) may be caused by landscape processes.

Table 1. Parameters of semivariogram and fitting model for forest types.

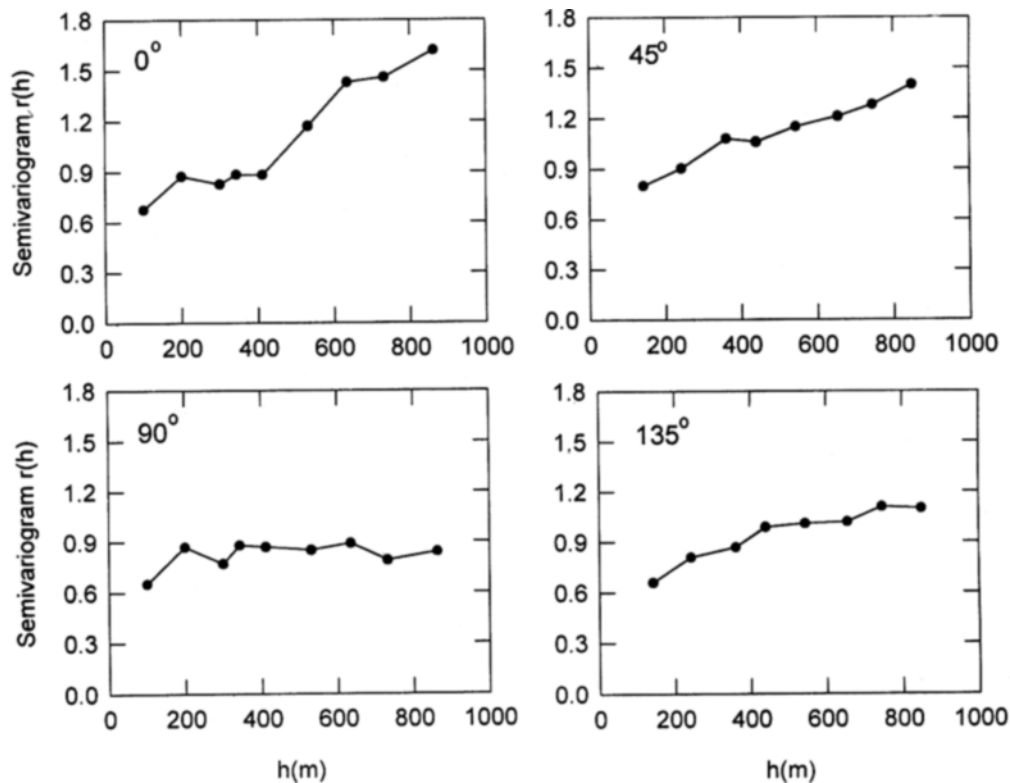| Parameters	Values
Model	Linear with sill
C	0.6200
$C+C$	1.2000
C_0/C_0+C	0.5166
a	718.0000
D	1.8500
RSS	0.0100
R	0.9740

Fig. 3 Semivarigrams of forest type in 0.45, 90 and 135 directions at landscape levels

The characteristics of semivariograms of forest types (Fig.3) in four directions show that there are a stronger anisotropic structure at different directions beyond the distances of 400 m. In direction of θ =0, an abrupt change in slope of a semivraiogram indicates that the variations of forest types may be controlled by several important processes operating at different scales, while the semivariogram in direction of θ =90, a flat curve indicates that a few processes may be equally important at all scales (Trangmar et al 1985, Webster 1985). Comparing fractal value (D=1.8500) with anisotropic structure, the landscape heterogeneity could be com-

plexity. Soil condition (e.g.. soil types and moisture) and microtopography(e.g.. low or high site) are an important factors which has effect on forest types. This is consistent with our field experience in sampled region. Thus, the differences of anisotropic semivariograms in the four directions(Fig.3) should represent real differences in the landscape.
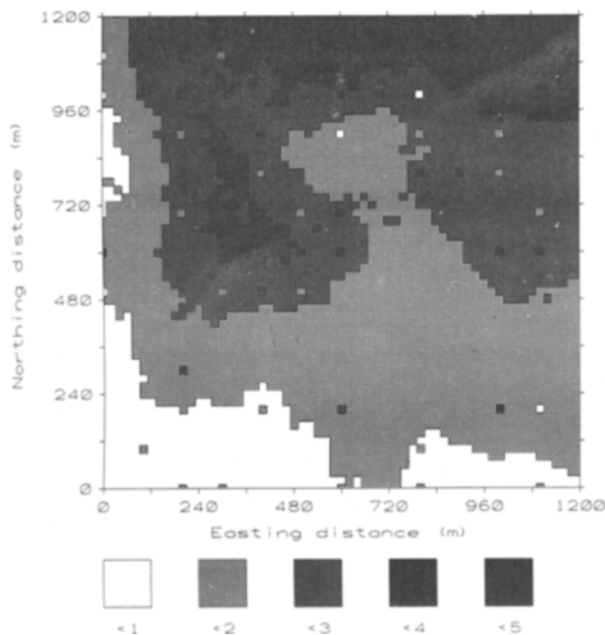

Fig. 4. A simulation of landscape pattern of old growth forest of Korean pine by block kirging.

1 Spruce-fir forests. 2 Spruce-Korean pine forests. 3 Libbed birch-korean pine forests. 4 Amur linden-korean pine forests. 5 Mongolian oak-Korean pine forests

Landscape, or spatial, heterogeneity lead up to landscape pattern(Forman et al 1986. Turner 1989), which is a scale-dependent pattern due to spatial heterogeneity is the function of scales. Kriging map(Fig.4) show the landscape patterns of old growth forests of Korean pine in sampled region. From south to north, the variation of topography, or gradients, is about 40-60 m. Soil moisture is from wet in low site to dry in hill or top site. The forest types or ecosystems, from spruce-fir forests in low-lying land to spruce-Korean pine forests, libbed birch-Korean pine forests. amur linden-Korean pine forests in hillside, and Mongolian oak-Korean pine forests in top site, were changed in series. The shape and size of pattern(Fig.4) show the characteristics of each forest types mosaic in old growth forest landscape, which indicate higher spatial heterogeneity. This forest mosaic or patches result from complex interactions between physical(e.g.. soil, topography) and biological(e.g.. competition, succession) forces(Turner 1989).

it is a unique phenomenon that emerges at the landscape level.

Fig. 5 illustrated the real spatial distributions of forest types, which were typed from datasheet of 144 plots and are very roughly using 100 m sampling interval. In kriging, there are about 3456 interpolated values with 20 m interval. The field data and interpolated values can be used for mapping spatial pattern through kriging mapping. It would have some error, but we should know that kriging is a technique of making optimal. unbiased estimates of regionalized variables at unsampled locations using the structural properties of the semivaiogram and the initial set of data values(Trangmar et al 1985), a useful feature of kriging is that an error term is calculated for each estimated value, providing a measure of the reliability of the interpolation. Comparing both Fig.4 and Fig.5, kriging technique is an effectiveness method for simulating distributions of forest types and to patterning in landscape.
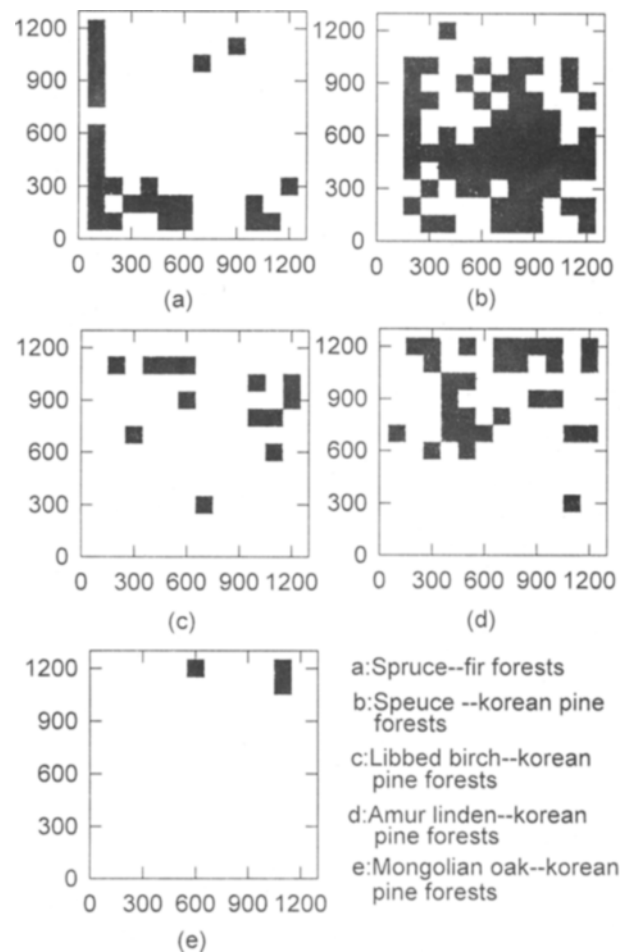

a:Spruce--fir forests

b:Speuce --korean pine forests

c:Libbed birch--korean pine forests

d:Amur linden--korean pine forests

e:Mongolian oak--korean pine forests

Fig. 5. Spatial distributions of forests types at landscape level in sampled region

Conclusion

Landscape ecology emphasizes broad spatial scales and ecological effects of the spatial patterning of eco-systems. Spatial pattern, which was operated by spatial heterogeneity, is the indicators of landscape and is an important in landscape ecological studies. Old growth forests of Korean pine are high degrees of spatial het-erogeneity at different scales and directions in land-scape level. The distribution of forest types in research region were scale-dependence and patterned in space. This spatial pattern which were mosiaced by forest types result from complex interactions between physi-cal (e.g., soil properties, topography) and biologi-cal(e.g., competition, succession) forces and processes in landscape level. Kriging is an effective technique to simulate landscape patterns of old growth forests of Korean pine.

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